Chemistry & STEM
Measurement II

Density

An Objects' Relationship of its Mass & Volume

Dr. Ron Rusay

Density

http://www.density.com/what.htm

Density = Mass / Volume [g/mL or g/cm³; g/L]

mass (*m*)

$$d = \frac{m}{V} = \frac{156\ \text{g}}{20.0\ \text{cm}^3} = 7.80\ \text{g/cm}^3$$

volume (*V*)

density (*d*)

Archimedes 250 B.C.E. Does iron float?.... The RMS Titanic?

Density

http://www.density.com/what.htm

Archimedes 250 B.C.E. Does iron float?.... The RMS Titanic?

NOVA: The Secrets of Archimedes
https://www.youtube.com/watch?v=0n347dxm5uE

NOVA: Why Do Ships Sink?
https://www.youtube.com/watch?v=n_xDZjrZ6zs

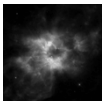
Density

Density = Mass / Volume [g/mL or g/cm³; g/L] (kg/m³)

Very Dense Astronomical Objects: White Dwarfs
http://antwrp.gsfc.nasa.gov/apod/ap961203.html

$D(\rho) = 1 \times 10^9\ \text{kg/m}^3 = 1 \times 10^3\ \text{kg/cm}^3$
$= 1 \times 10^6\ \text{g/cm}^3$

A White Dwarf's mass is comparable to our Sun's, but its volume is about a million times smaller; the average density is ~1,000,000 times greater than the Sun's 1.4 kg/m³



Our Sun will eventually become a white dwarf "butterfly"….. but not for ~5 billion years.

Dimensional Analysis
Conversion/Unit Factor Calculations

- *Using exact numbers / "scale factors" UNITS*
- *A Bookkeeping Process: Example*

  Calculating the density [D(ρ) = ? g/cm³] of a white dwarf, 1.0 x 10^9 kg / 1 m^3
- ***(1 kg = 1000g; 1 m³ = 1 x 10⁶ cm³; 1 Ton (T) = 1000kg)***

$$\frac{\frac{kg}{m^3}\ \Big|\ \frac{m^3}{cm^3}\ \Big|\ \frac{g}{kg}}{\frac{?\ g}{?\ cm^3}}$$

Dimensional Analysis
Conversion/Unit Factor Calculations

- *Using exact numbers / "scale factors" UNITS*
- *A Bookkeeping Process: Example*

  Calculating the density [D(ρ) = ? g/cm³] of a white dwarf, 1.0 x 10^9 kg / 1 m^3
- ***(1 kg = 1000g; 1 m³ = 1 x 10⁶ cm³; 1 Ton (T) = 1000kg)***

$$\frac{\frac{1.0 \times 10^9\ kg}{1\ m^3}\ \Big|\ \frac{1\ m^3}{cm^3}\ \Big|\ \frac{1{,}000\ g}{1\ kg}}{\frac{?\ g}{?\ cm^3}} = \frac{1{,}000{,}000 = 1.0 \times 10^6}{1}$$

$1.000 \times 10^6 = (100\ cm)^3$

Dimensional Analysis
Continued

- *Example for an astronomical object where 1 teaspoon weighs 3 Tons. (~ 3 pick up trucks).*
  3 T /1 tsp ⟶ ? g/cm³
- *(1 tsp = 4.9289 mL; 1 T (Ton) = 1,000 kg; 1 kg = 1,000 g; 1 mL = 1 cm³)*

T	tsp	mL	kg	g	=	? g
tsp	mL	cm³	T	kg		? cm³

Dimensional Analysis
Continued

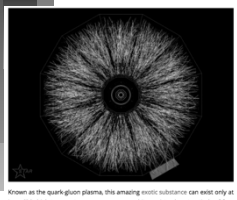
- *Example for an astronomical object where 1 teaspoon weighs 3 Tons. (~ 3 pick up trucks).*
  3 T /1 tsp ⟶ ? g/cm³
- *(1 tsp = 4.9289 mL; 1 T (Ton) = 1,000 kg; 1 kg = 1,000 g; 1 mL = 1 cm³)*

1.000 x 10³ 1.000 x 10³

3 T	1 tsp	1 mL	kg	g	=	? g
1 tsp	mL (4.9289)	1 cm³	1 T	1 kg		? cm³

6 x 10⁵ g/cm³

Density
Density = Mass / Volume [g/mL or g/cm³; g/L; kg/m³]



Known as the quark-gluon plasma, this amazing exotic substance can exist only at incredibly high temperatures or pressures, and it consists almost entirely of free quarks and gluons; it is possible that the whole universe was filled only with this substance in the immediate aftermath of the Big Bang.

"Besides black holes, there's nothing denser than what we're creating," said David Evans, a team leader for the Large Hadron Collider's ALICE detector, which helped observe the quark-gluon plasma shown. "If you had a cubic centimeter of this stuff, it would weigh 40 billion tons."

http://www.zmescience.com/science/physics/quark-gluon-plasma-lhc-26052011/#ixzz3foandtPt

How does quark-gluon plasma's density compare to a white dwarf? (1 ton = 1,000 kg)

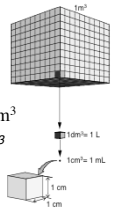
Calculate the density [D(ρ) = ?] (kg/cm³…or g/cm³..or kg/m³) of quark-gluon plasma: 1 cm³ has a mass of 4.0 x 10^{10} T (metric tons) ***4.0 x 10^{10} greater*** for comparison to White Dwarf.

(1 T = 1,000 kg; 1 kg = 1,000g; 1,000,000 cm³ = 1 m³)

$$\frac{4.0 \times 10^{10}\ \text{T}}{\text{cm}^3} \left| \frac{\mathbf{1{,}000\ kg}}{\mathbf{T}} \right. = 4.0 \times 10^{13}\ \text{kg/cm}^3 \qquad \textit{1 x 10}^{3}\ \textit{kg/cm}^3$$

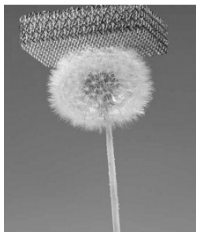
$$\frac{4.0 \times 10^{10}\ \text{T}}{\text{cm}^3} \left| \frac{\mathbf{1{,}000\ kg}}{\mathbf{T}} \right| \frac{\mathbf{1{,}000\ g}}{\mathbf{kg}} = 4.0 \times 10^{16}\ \text{g/cm}^3 \qquad \textit{1 x 10}^{6}\ \textit{g/cm}^3$$

$$\frac{4.0 \times 10^{13}\ \text{kg}}{\text{cm}^3} \left| \frac{\mathbf{1{,}000{,}000\ cm^3}}{\mathbf{m^3}} \right. = 4.0 \times 10^{19}\ \text{kg/m}^3 \qquad \textit{1 x 10}^{9}\ \textit{kg/m}^3$$



Density: Ultralight microlattices
Density = Mass / Volume [g/mL or g/cm³; g/L; kg/m³]

T. A. Schaedler et al. Science 2011;334:962-965



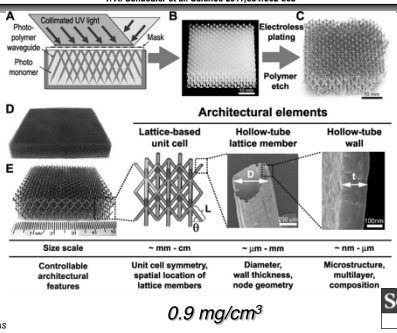
http://www.gizmag.com/ultralight-micro-lattice-material/20537/

0.9 mg/cm³ (air = 1.2 mg/cm³)

Published by AAAS

Engineering Ultralight Microlattices
Density = Mass / Volume [g/mL or g/cm³; g/L; kg/m³]

T. A. Schaedler et al. Science 2011;334:962-965

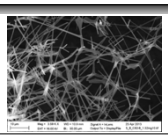


0.9 mg/cm³

Published by AAAS

Density

Density = Mass / Volume [g/mL or g/cm³; g/L; kg/m³]



- *Aerographite is a synthetic foam consisting of a porous interconnected network of carbon nanotubes. It was first reported by researchers at the University of Kiel and the Technical University of Hamburg in Germany in a scientific journal in June 2012. It's density is:*
- *D = 0.18 mg/cm³*

Density

Density = Mass / Volume [g/mL or g/cm³; g/L; kg/m³]

https://www.youtube.com/watch?v=3bIXUBXj070

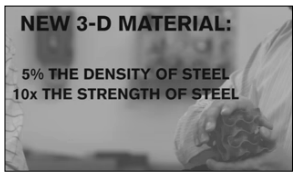
0.16 mg/cm³

Chao Gao et. al., Zhejiang University, Department of Polymer Science and Engineering
Nature 494, 404 (28 February 2013)
doi:10.1038/494404a

Density

Density = Mass / Volume [g/mL or g/cm³; g/L; kg/m³]

https://www.youtube.com/watch?v=VlcZdc42F0g



Structural 3-D Graphene
One of the strongest lightweight materials known
MIT: January 2017

QUESTION

A metal sample is hammered into a rectangular sheet with an area of 31.2 ft² and an average thickness of 2.30 × 10⁻⁶ cm. If the mass of this sample is 0.4767 g, predict the identity of the metal.

The density of the metal is shown in parenthesis.
Useful information: 1 ft = 12 in; 1 in = 2.54 cm

A) Aluminum (2.70 g/cm³) ***B) Copper (8.95 g/cm³)***

C) Gold (19.3 g/cm³) ***D) Zinc (7.15 g/cm³)***

Dimensional Analysis

Conversion/Unit Factor Calculations

A metal sample is hammered into a rectangular sheet with an area of 31.2 ft² and an average thickness of 2.30 × 10⁻⁶ cm. If the mass of this sample is 0.4767 g, predict the identity of the metal.

- *The density of the metal is shown in parenthesis.*
- *Useful information: 1 ft = 12 in; 1 in = 2.54 cm*

$$\frac{ft^2}{\;} \left| \frac{in^2}{ft^2} \right| \frac{cm^2}{in^2} \left| \frac{cm}{\;} \right| = \; ?$$

Dimensional Analysis

Conversion/Unit Factor Calculations

A metal sample is hammered into a rectangular sheet with an area of 31.2 ft² and an average thickness of 2.30 × 10⁻⁶ cm. If the mass of this sample is 0.4767 g, predict the identity of the metal.

- *The density of the metal is shown in parenthesis.*
- *Useful information: 1 ft = 12 in; 1 in = 2.54 cm*

$$31.2\ ft^2 \left| \frac{12 \times 12}{\frac{in^2}{ft^2}} \right| \frac{2.54 \times 2.54}{\frac{cm^2}{in^2}} \left| \frac{2.30 \times 10^{-6}}{cm} \right| = \; 0.066667222\ cm^3$$

$$6.67 \times 10^{-2}\ cm^3$$

$$0.4767\ g / 6.67 \times 10^{-2}\ cm^3 = 7.15\ g/cm^3$$

*Densities of Various Common Substances**

Densities of Various Common Substances* at 20°C

Substance	Physical State	Density (g/cm³)
Oxygen	Gas	0.00133
Hydrogen	Gas	0.000084
Ethanol	Liquid	0.789
Benzene	Liquid	0.880
Water	Liquid	0.9982
Magnesium	Solid	1.74
Salt (sodium chloride)	Solid	2.16
Aluminum	Solid	2.70
Iron	Solid	7.87
Copper	Solid	8.96
Silver	Solid	10.5
Lead	Solid	11.34
Mercury	Liquid	13.6
Gold	Solid	19.32

*At 1 atmosphere pressure

QUESTION

Which would provide more grams of NaCl, sample one with a mass of 2,350 mg, or sample two, a solid with a volume of 2.00 cm^3? (The density of solid salt is 2.16 g/cm^3.) Select the most massive sample and its mass in grams.

A. Sample two; 1.08 grams
B. Sample two; 4.32 grams
C. Sample one; 2.35 grams
D. Sample one; 2.350 grams

QUESTION

The volume of any material can be obtained from its density and mass.

If the mass of a sample of acid from a battery were 5.00 grams and its density was 1.2 g/mL, what would the correct reported volume in mL with the proper number of significant digits?

A. 6.0 mL
B. 6.00 mL
C. 4.2 mL
D. 4.17 mL

Density

Density = Mass / Volume [g/mL or g/cm^3; g/L]

Mass = Density x Volume

- *How many grams of air are there in PS 275?*
- *The room has dimensions of ~ 3.5 m x 11 m x 10. m.*
- *D_{air} = 1.22 x 10^{-3} g/cm^3 (1.22 g/L)*
- *$1m^3$ = 100 cm x 100 cm x 100 cm;*
- *1000 cm^3 = 1 L; 1 mL = 1 cm^3*

A. 1.22 x 10^3 g
B. 385,000,000 g
C. 3.85 x 10^6 g
D. 47,000,000 g
E. 4.70 x 10^8 g

Dimensional Analysis

Conversion/Unit Factor Calculations

- *How many grams of air are there in PS 275?*
- *The room has dimensions of ~ 3.50 m x 11.0 m x 10.0 m. = 385 m^3*
- *D_{air} = 1.22 x 10^{-3} g/cm^3 (1.22 g/L)*
- *$1m^3$ = 100 cm x 100 cm x 100 cm;*
- *1000 cm^3 = 1 L; 1 mL = 1 cm^3*

$$385\ m^3 \left| \frac{1 \times 10^6\ cm^3}{1\ m^3} \right| \frac{1.22\ g}{1\ cm^3} = 470. \times 10^6\ g \text{ or } 4.70 \times 10^8\ g$$

QUESTION

General Chemistry Level Challenge

Density

Density = Mass / Volume [g/mL or g/cm^3; g/L]

- *How many pounds of air are there in PS 275? It has a volume of ~220 yd^3.*
- *D_{air} = 1.22 x 10^{-3} g/cm^3 (1.22 g/L)*
- *If the room were filled with pure oxygen, there will be more pounds of gas in the room. True/False: (Explain the reason(s) for your answer.)*

QUESTION

General Chemistry Level Challenge

Titanium is abundant in the earth's crust, but horrendously difficult to turn into a bicycle frame. From extraction, to final welding and finishing, titanium is fraught with very complex processes that are as expensive as they are essential. One slip, omission on behalf of the mill, machinist, welder or finisher or the slightest contamination of oxygen, nitrogen, and hydrocarbon (i.e. human fingertips) at the wrong time and the frame will almost certainly fail at some point. Hence most bike companies don't use titanium.

http://cyclefit.co.uk/journal/5-questions-to-ask-before-buying-a-titanium-bike

QUESTION

General Chemistry Level Challenge

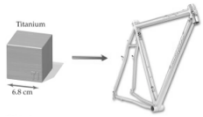
However, titanium's tolerance to cyclical load is infinite. This is a huge advantage both in terms of safety and for ride quality. It means that as long as the tube spec and frame design is well executed, a bicycle will offer exceptional comfort, performance and ride the same in its first mile as its millionth!

- *Titanium is much lighter than steel alloy, which has been commonly used in frames.*
- *Titanium (4.50 g/cm^3); steel alloy (7.75 g/cm^3).*

http://cyclefit.co.uk/journal/5-questions-to-ask-before-buying-a-titanium-bike

QUESTION

General Chemistry Level Challenge



$4,199.00

- *A titanium bicycle frame contains the same amount of titanium as a titanium cube measuring 6.8 cm on a side.*
- *Use the density of titanium to calculate the mass in kilograms of titanium in the frame.*
- *What would be the mass of a similar frame composed of steel alloy?*

Titanium (4.50 g/cm^3); Steel alloy (7.75 g/cm^3).

QUESTION

General Chemistry Level Challenge

$9,000.00 frame

- *A stiff light weight carbon fiber bicycle frame is said to weigh as little as 690g.*
- *Carbon fiber frames are the mainstay of the Tour de France.*

•What is the percent difference in the weight of a carbon fiber frame versus titanium?
•What is the relative cost per kg for each of them?
•Assuming the volume of carbon fiber in the frame is equal to titanium, what is the density of the carbon fiber?

QUESTION

General Chemistry Level Challenge

http://chemconnections.org/general/chem108/3D%20printing%20transforms%20the%20economics%20of%20manufacturing.pdf

http://chemconnections.org/general/chem108/3D%20printers%20start%20to%20build%20factories%20of%20the%20future.pdf

Weighty matters

	Value of weight saving, $/kg
F1 motorsport	More than 120,000
Spacecraft	25,000
Aircraft	1,200-13,000
Automotive	20-600
Trucks, excavators, etc	1.3-12.7
Factory equipment	0-6

Source: Marcus Pont, Domin Fluid Power, 2017

Economist.com

Reducing weight offers large returns besides winning the Tour de France.

Read the linked articles above, and briefly explain how 3D printing relates to these savings in one or more of the examples from the table. Also, are there any opportunities in your chosen career path for 3D printing applications?